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**STATUS OF LOBSTER STOCKS IN THE NORTHWESTERN  
HAWAIIAN ISLANDS, 1995-97, AND OUTLOOK FOR 1998**

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## INTRODUCTION

Crustacean fisheries within the U.S. Exclusive Economic Zone (EEZ) in the Western Pacific (Hawaii, American Samoa, and Guam) are managed by the Western Pacific Regional Fishery Management Council (Council) under the Fishery Management Plan for the Crustaceans of the Western Pacific Region (Crustaceans FMP). Most crustacean landings come from the Northwestern Hawaiian Islands (NWHI) lobster fishery which targets the Hawaiian spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) (Fig. 1). The status of the NWHI lobster stocks has been assessed by the National Marine Fisheries Service, Honolulu Laboratory (NMFS-HL) on an annual basis since the implementation of the Crustaceans FMP in 1983. This report describes the present status of lobster stocks in the NWHI and summarizes the results of research conducted from 1995 through 1997 to determine stock status. Estimates of the total exploitable population of spiny and slipper lobster (species combined) in the NWHI on July 1, 1998 are presented and procedures used to compute the total exploitable population are described. These estimates are used by the NMFS Southwest Regional Director to determine the harvest guideline for the 1998 NWHI commercial lobster fishing season. For the 1998 fishing season, the estimate of total exploitable population is the sum of exploitable population estimates computed separately for four regions in the NWHI. This represents a departure from previous procedures (archipelago wide) used to compute total exploitable population in the NWHI. Continuing differences in recruitment patterns and species composition between the northwestern and southeastern segments of the NWHI demonstrate the need for region-specific estimation of exploitable population size. The development of spatially structured estimates of exploitable population and harvest guidelines is also consistent with the recommendations of a Fishery Review Panel convened in March 1997 to evaluate stock assessment and management of lobsters in the NWHI. The review panel's recommendations were later endorsed by the Council and various Council advisory committees.

Before proceeding, a number of terms referred to in this report should be defined. Mature spiny and slipper lobsters are lobsters  $\geq 50$  mm tail width (TW) and  $\geq 56$  mm TW, respectively. Immature spiny and slipper lobsters are those that are  $< 50$  mm TW and  $< 56$  mm TW, respectively. Berried lobsters (spiny or slipper lobster) are females carrying extruded eggs.

## RESOURCE MONITORING AND RESEARCH

Commercial catch and effort data, as well as pertinent operational aspects of the fishery, are discussed. In addition, fishery-dependent and fishery-independent research conducted by the NMFS-HL between 1995 and 1997 is described and key findings presented.

## Commercial Catch and Effort Data

To provide fishery information for stock assessment and management purposes, vessel captains have been required under Amendment 1 of the Crustaceans FMP to submit a trip logbook with data on daily catch (in numbers), lobsters retained (landings), and fishing effort (number of traps hauled), providing a 15-year time series. Total reported catch and landings of lobsters peaked in 1985 at approximately 2,736,000 and 2,031,000 lobsters, respectively, and generally declined from 1986 to 1995 (Table 1; Fig. 2). Fishing effort peaked in 1986 at approximately 1,290,000 trap hauls and declined to 834,000 trap hauls in 1988 before increasing to 1,180,000 trap hauls in 1990. After 1990 fishing effort generally declined.

The fishery initially targeted spiny lobster, but by 1984 gear modifications and improved markets led to an increase in slipper lobster landings. Catches of slipper lobster remained high from 1985 to 1987, fell into a general decline from 1988 to 1996, and increased significantly in 1997 (Fig. 3).

The proportion of fishing effort and reported catch at each bank within the NWHI has varied both spatially and temporally. While as many as 16 banks within the NWHI were fished on an annual basis, the majority of fishing effort has been directed at 4 banks: Maro Reef, Gardner Pinnacles, St. Rogatien, and Necker Island. Between 1984 and 1989 most of the fishing effort was directed at Maro Reef (Fig. 4). After 1989, fishing effort decreased at Maro Reef and increased significantly at Gardner Pinnacles and Necker Island. In 1997, most of the fishing effort was directed at Necker Island (64%), followed by Maro Reef (23%), Gardner Pinnacles (13%), and St. Rogatien (<1%).

In general, the observed spatiotemporal shifts in fishing effort between banks are attributed to declines in spiny lobster CPUE; as spiny lobsters were fished down and catch rates at a particular bank fell below some minimum economic threshold, fishing effort shifted to more productive banks. During the most recent years fishing has generally been limited to Necker Island where there has been a relatively higher concentration of spiny lobsters.

As early as 1980, problems with high catch rates of small, immature lobsters and associated discard mortality were identified (MacDonald and Stimson, 1980). The requirement for traps to include escape vents was mandated in 1987. From 1983 through 1995 the lobster (spiny lobster and slipper lobster combined) discard rate (the reported ratio of lobsters discarded to total lobsters caught) generally increased, rising from 0.28 in 1983 to 0.62 in 1995 (Fig. 5). After 1995, the discard rate decreased significantly when the minimum legal size requirement was relaxed in favor of an optional retain-all policy. Implementation of a retain-all policy was accompanied by research conducted by the NMFS-HL in 1996 to determine the effects of shipboard handling on the mortality of sublegal and berried lobster. The results are discussed later in this report.

### **1995-97 Fishery-Dependent Research**

To support stock assessments, ancillary information was collected from the commercial fishery between 1995 and 1997. In 1995 NMFS opened a limited commercial fishery under an experimental permit issued to the single vessel that applied. The commercial fishery operated under the guidelines of Amendment 7 to the Crustaceans FMP and the quota was set at 36,000 lobsters. The experimental permit stipulated that the vessel expend a predetermined level of effort at each of the three major fishing areas in the NWHI (Necker Island, Maro Reef, and Gardner Pinnacles) and also carry a NMFS biological technician. For each decked lobster the biological technician collected information on the species, sex, reproductive condition, and market category (legal or sublegal). In addition, 50 lobsters were randomly selected from the catch of each string of traps. Each lobster's tail width and carapace length were measured and its reproductive condition recorded. The biological technician also reported on daily fishing, catch sorting, and discard methods.

The locations of strings sampled at Necker Island during the 1995 commercial fishery are shown in Figure 6. The bank surrounding Necker Island was delineated into seven statistical areas based on reported commercial fishing areas. Spatial differences in spiny lobster mean tail width and percent berried were observed between areas (Table 2). Spiny lobsters from statistical areas 4 and 5 were generally larger than spiny lobsters from statistical areas 1 and 2. Spiny lobsters from statistical area 3 were intermediate in size. A greater proportion of berried lobsters were caught in statistical areas 4 and 5 compared to areas 1, 2, and 3.

The 1996 and 1997 commercial fisheries operated under the guidelines of Amendment 9 to the Crustaceans FMP, which allowed the retention of juvenile and berried lobsters. The harvest guideline was set at 186,000 lobsters in 1996 and 322,912 lobsters in 1997. A pilot shoreside monitoring program to sample commercial lobster landings was conducted in 1996 and 1997 by the NMFS-HL. Approximately 300 measurements of tail width, tail weight, sex, and reproductive condition were collected at random from each vessel's lobster landings intercepted at wholesalers. Tail width-tail weight regressions, stratified by sex and reproductive condition, were computed. Another 2,000 measurements of tail weight, sex, and reproductive condition were collected from random samples of lobsters and tail widths estimated using the developed regressions.

A voluntary data collection program was implemented in 1997 and NMFS biological technicians were placed on 6 of the 9 vessels participating in the 1997 fishery. Approximately 50 lobsters were randomly selected from the catch of each trap string; for each sampled lobster, tail width and reproductive condition were recorded. The biological technicians also reported on daily fishing, sorting, and discard methods.

## **1995-97 Fishery-Independent Research**

A fishery-independent trap survey was conducted annually from 1984 to 1989, and 1991 to 1997, by the NMFS-HL to collect length frequency, sexual development, and distributional data from lobster stocks in the NWHI. The survey has also been used to (1) evaluate the performance of commercial and research survey gear, (2) calibrate gear types, and (3) provide a platform for experiments. The survey uses a fixed-site design stratified by depth. At each site, shallow (< 20 fathoms) and deep ( $\geq$  20 fathoms) stations are sampled. Ten strings of 8 traps each are set at the shallow station and two to four strings of 20 traps each are set at the deep station. Traps are fished overnight and baited with 1.5-2.0 pounds of cut-up, previously frozen mackerel. Data on species, tail width, sex, and reproductive condition (berried or unberried) are collected for each lobster caught, as well as the latitude and longitude of the traps, recorded at the string level.

Fathom Plus® black plastic traps were introduced into the commercial fishery in the early-1980s and quickly replaced the California two-chambered wire trap to become the standard commercial gear. These black plastic traps, minus any escape vents, were first used in the research survey in 1985, and since 1992 have been used exclusively. A trap comparison study was conducted by the NMFS-HL in 1991 to provide a conversion formula for wire and plastic trap CPUE (Haight and Polovina, 1992).

Between 1995 and 1997, standard research trapping was conducted at Maro Reef and Necker Island (Figs. 7 and 8), and exploratory trapping for juvenile lobsters conducted in the shallow lagoon at Maro Reef. In 1996, limited standard research trapping was also conducted at Laysan Island. The NMFS-HL also conducted research to estimate lobster discarding during the 1996 commercial fishing season and to provide provisional estimates of shipboard lobster handling mortality. Below we present the key findings from the juvenile lobster exploratory trapping, discard, and handling mortality studies. The results from standard research trapping are discussed in a later section of this report.

## **Juvenile Lobster Exploratory Trapping**

In 1993, the NMFS-HL began exploratory trapping of juvenile spiny lobster in the shallow reef areas of Maro Reef during the NMFS-HL fishery-independent trap survey to determine if indices of juvenile spiny lobster relative abundance (CPUE) could be used as an index of recruitment to Maro Reef and as a tool to forecast recruitment to the Maro Reef commercial fishery. Constraints on trap survey operations from small boats during the annual trap surveys prevent the collection of a sample size large enough to detect a 50% difference in mean juvenile CPUE between years or significant trends in CPUE within a realistic time frame (Haight, 1998). As a result, juvenile lobster exploratory trapping at Maro Reef has been discontinued.

## **Handling Mortality**

Handling mortality for immature spiny and slipper lobsters and berried spiny and slipper lobsters were studied during the 1996 lobster assessment cruise. Handling mortalities were estimated for two on-deck handling methods (dry and wet) and a variety of exposure times. Handling mortality was estimated to be as high as 77% for spiny lobsters and 44% for slipper lobsters depending on the duration of exposure after being hauled on deck (DiNardo and Haight, 1996).

## **Discard Estimation**

We assessed the utility of using 1995 and 1996 ancillary fishery-dependent and fishery-independent data to estimate the amount of lobsters discarded during the 1996 commercial fishing season. Discard estimation was based on a synthesis of gear selectivity curves, retention curves for the fleet, and estimates of trappable population size. Although the analytical approach used by the NMFS-HL was sound (WPRFMC, 1997), its annual lobster assessment cruise does not provide the data required to accurately estimate trappable population size structure (DiNardo, 1997). The spatial distribution of sampling effort in the research survey was inconsistent with the spatial distribution of commercial fishing effort, and spatial heterogeneity within the lobster population is believed to be operating at scales very different from those observed in the research survey.

## **INDICES OF ABUNDANCE**

### **Commercial Fishery Data**

Lobster CPUE (pooled across all banks) declined from 2.75 lobsters/trap haul in 1983 to 0.98 lobsters/trap haul in 1987, then increased to 1.26 lobsters/trap haul in 1988 before declining to an average of 0.63 lobsters/trap haul between 1991 and 1995 (Fig. 9). CPUE increased to 1.62 lobster/trap haul in 1996 and 1.75 lobsters/trap haul in 1997. This sudden increase in reported CPUE during the 1996 and 1997 fishing seasons resulted from changes in fishery policies and not significant increases in the population. The 1996 and 1997 commercial fisheries operated under the guidelines of Amendment 9 which allowed all lobsters caught and decked to be landed. Also, most of the fishing effort in 1996 and 1997 was directed at Necker Island, the most productive bank. In addition, areas with higher concentrations of slipper lobster were specifically targeted by some participants during the 1997 commercial fishery, representing a change in fishing strategy. In previous years minimum size limits were imposed and fishing occurred on several banks, including less productive banks. Reevaluating the 1996 and 1997 CPUEs by assuming historical minimum legal sizes results in a hypothetical 1996 and 1997 CPUE of 1.3 (Fig. 9).

To assess exploitable population size by bank, we have decomposed the pooled commercial CPUE time series into bank-specific legal-lobster CPUE, catch, and fishing effort time series. While as many as 16 banks within the NWHI have historically been fished, not all have been fished continuously and the reported CPUE time series are from banks in which at least 5 years of commercial fishing data are available. A feature common to all reported series is a declining trend in CPUE (Fig. 10). For many of the banks a 50% drop in CPUE was reported between 1983 and 1987. Such trends in CPUE may be indicative of overfishing, and while there is not conclusive evidence at this time to assess specific causes for the observed declines in NWHI lobster CPUEs, excessive fishing mortality likely contributed significantly to the declines.

### **NMFS-HL Fishery-Independent Trap Survey Data**

The efficacy of the NMFS-HL fishery-independent trap survey to provide accurate metrics of relative abundance has yet to be assessed, and caution is advised when interpreting the survey data. Detailed analyses to determine the efficacy of the trap survey to provide accurate metrics of relative abundance are forthcoming. Provisional results are presented here for completeness.

Because of difficulties in computing reliable converted plastic trap CPUEs for spiny and slipper lobster we limited our computation of CPUEs to years in which plastic traps were fished in significant numbers at both shallow and deep stations ( $\geq 50\%$  of the total traps fished). For Maro Reef this corresponds to years 1987-97 and for Necker Island, years 1988-97.

Since 1990, Necker Island spiny lobster CPUEs have generally decreased. Significant drops in CPUE were observed in 1992 and 1994 (Fig. 11). At this time we cannot determine if the 1997 drop in CPUE represents a downward trend or is merely a reflection of natural interannual variability. Slipper lobster CPUEs have remained at relatively low levels at Necker Island between 1988 and 1997 (Fig. 11).

Spiny lobster CPUEs at Maro Reef declined significantly after 1988 and have since remained low. Slipper lobster CPUEs at Maro Reef have generally been increasing, with significant increases occurring after 1991 (Fig. 12). The apparent switch in species dominance at Maro Reef may suggest a replacement by slipper lobster as spiny lobster were fished down and habitat became available to slippers. However, causes for the switch will require additional analysis.

### **Factors Affecting Abundance**

In predicting the response of the NWHI lobster population to commercial harvest it must be noted that research to date has identified a dynamic change in the spatial and temporal structure of the NWHI lobster population. One major fishing area, Maro Reef, which for many years was the mainstay of the spiny lobster fishery, continues to be



characterized by low spiny lobster abundance. Based on oceanographic research, size class and genetic structure analysis, and CPUE trends it appears that recruitment in the NWHI spiny lobster population differs between the southeastern and northwestern segments of the archipelago and remains low in the northwestern segment relative to the 1975-85 level. Numerous hypotheses have been advanced to explain population fluctuations of lobsters in the NWHI including environmental (Polovina and Mitchum, 1992), biotic (e.g., habitat and competition) (Parrish and Polovina, 1994), and anthropogenic (e.g., fishing) (Polovina et al., 1995). Each hypothesis by itself offers a plausible, however simplistic, explanation of events that in fact result from several processes acting together. It is likely that population fluctuations of lobsters in the NWHI can be more accurately described by a mix of the hypotheses presented, each describing a different set of mechanisms.

Despite our lack of understanding the mechanisms controlling lobster populations in the NWHI, the current nature of the fishery (targeting selected banks in both the northwestern and southeastern segments of the archipelago) and areal differences in recruitment patterns and species composition are compelling reasons to assess population size and manage harvests on a region-specific basis. Continuing with the status quo (archipelago-wide management) ignores the inherent spatial heterogeneity and increases the chances of localized overfishing.

## **STOCK ASSESSMENT**

### **Criteria for Assessing Stock Status**

Regulatory guidelines for fishery management in the United States under the Sustainable Fisheries Act require that definitions of overfishing be established and criteria to assess overfishing be developed. Overfishing in the Crustaceans FMP is defined in terms of recruitment overfishing, and the criterion used to assess overfishing is the spawning potential ratio (SPR) (Goodyear, 1980; 1993). The SPR is the ratio of the spawning potential of a cohort in a fished condition relative to that in an unfished condition. SPR is inversely proportional to fishing effort, varying from 1 (when there is no fishing) to 0 (with infinite fishing). There are two established SPR thresholds in the Crustaceans FMP, a 0.20 minimum SPR threshold level below which the stock is considered overfished and a warning range from 0.20 to 0.50 indicating the need for additional conservation measures.

The spawning potential of NWHI lobsters is measured as spawning stock biomass per recruit and computed using an equilibrium spawning biomass-per-recruit equation (Beverton and Holt, 1957). Hence, the determination of whether or not a stock is above or below the SPR thresholds is made assuming equilibrium conditions; i.e., the equilibrium SPR resulting from constant fishing mortality rates and biological parameters. The numerator of the current SPR level is the spawning potential that would be realized if the fishery continued to operate at a constant fishing mortality equal to that in the current year; the denominator is the spawning potential that would be realized if there were no fishing.

We have computed SPR values for two banks within the archipelago: Necker Island and Maro Reef. Historically, SPR was expressed as a pooled NWHI archipelago-wide estimate which neglects the spatial heterogeneity of the population and fishing effort. Spatially structured SPRs are likely to be more representative of the effects of fishing since they account for more of the spatial heterogeneity than pooled estimates.

Computing SPRs for the NWHI lobster requires estimates of fishing mortality, computed as  $q \cdot f$ , where  $q$  is the catchability coefficient and  $f$  is fishing effort (trap hauls). Catchability per trap haul for Necker Island and Maro Reef was  $2.1 \times 10^{-6}$  and  $1.9 \times 10^{-6}$ , respectively, and was derived by fitting a discrete population model (see Appendix) to monthly commercial catch and effort data from 1983 to 1997. The catch data included mature unberried spiny and slipper lobsters. The model used to estimate bank-specific parameters is the same model that has been used previously to compute estimates of exploitable population using archipelago-wide aggregated data.

Alternative estimates of catchability at Necker Island and Maro Reef were also derived exclusively from data collected during the 1997 commercial lobster fishery. Applying a closed-population Leslie depletion estimator (Leslie and Davis, 1939) to the 1997 daily commercial catch (mature unberried spiny and slipper lobsters) and effort data catchability estimates of  $4.7 \times 10^{-6}$  and  $2.0 \times 10^{-5}$  were derived for Necker Island and Maro Reef, respectively. If these estimates are used in the SPR equation the results indicate that for a number of years the population may have been overfished ( $\text{SPR} \leq 0.2$ ). The accuracy of the depletion estimates of catchability coefficients has not been fully investigated and requires additional study.

### **Status of the NWHI Lobster Stocks during 1995-97**

Based on SPR and relative abundance data the current status of the NWHI lobster stocks can be summarized as follows.

- ! The calculated 1995-97 SPR values for mature unberried lobsters from Necker Island and Maro Reef are above the minimum threshold, indicating that the levels of fishing effort exerted during the 1995-97 commercial fishing seasons and resulting fishing mortality and exploitation rate would be insufficient to cause long-term recruitment overfishing under equilibrium conditions (Table 3). The more recent SPRs from Necker Island are at the upper limit of the warning range, suggesting that additional conservation measures may be needed. SPR time series for unberried mature lobsters from the two banks are depicted in Figure 13. While we present SPR values from 1983 to the present it should be noted that the NWHI lobster fishery has been managed to prevent recruitment overfishing by maintaining the SPR above the 0.20 minimum threshold level only since 1990. At Necker Island the SPR declined from 0.75 in 1983 to 0.21 in 1990 and has since increased. In 1997 it was 0.52 (Table 3, Figure 13). SPR at Maro Reef declined from 0.94 in 1983 to 0.27 in 1988 and has also increased since then. In 1997 it was 0.83.

- ! At Necker Island spiny lobster is the dominant species, whereas at Maro Reef slipper lobster is dominant.
- ! Spatial differences in recruitment patterns between the northwestern and southeastern regions of the archipelago are apparent, suggesting that the mechanisms controlling population fluctuations differ between the two areas.
- ! The spatiotemporal shifts in fishing effort to exploit more productive banks may disguise actual trends in abundance at the archipelago level and individual banks.
- ! Localized overfishing may have occurred at the bank level.
- ! Numerous hypotheses have been advanced to explain population fluctuations of lobsters in the NWHI including environmental, biotic (e.g., habitat and competition), and anthropogenic (e.g., fishing). It is likely that population dynamics will be more accurately described by a mix of the hypotheses, each describing a different set of mechanisms.

### **ESTIMATE OF THE EXPLOITABLE POPULATION OF LOBSTERS IN THE NORTHWESTERN HAWAIIAN ISLANDS**

The procedures used to compute the total exploitable population for the 1998 NWHI commercial lobster fishing season are described. Total exploitable population is defined as the abundance of lobsters that are vulnerable to commercial fishing gear. This is the first year in which the assessment of NWHI lobster populations and estimation of exploitable population size have been conducted on an area-specific (region or bank) basis. This approach was recommended by scientific review panels, the Western Pacific Regional Fishery Management Council, and various Council advisory committees.

The area-specific population assessment allows harvest guidelines to be separately computed for each area. Assuming that catches in each area could be adequately monitored and controlled, the area-specific approach would provide greater assurances that the risk of overfishing lobster in each area would not exceed the risk level of 10% adopted by the Council in Amendment 9 of the Crustaceans FMP. On the contrary, in the absence of area-specific harvest guidelines and catch monitoring, application of a single, archipelago-wide harvest guideline is likely to result in a risk of overfishing exceeding 10% in one or more areas of the archipelago. To compute area-specific harvest guidelines, the harvest rate adopted by the Council in Amendment 9 to the Crustaceans FMP (13%) would be multiplied by the area-specific exploitable population estimates.

The Honolulu Laboratory has estimated that the total exploitable population of spiny and slipper lobsters (species combined) in the NWHI on July 1, 1998 will be 1,153,000 lobster. The estimate of total exploitable population of lobster is the sum of exploitable population estimates computed separately for four areas of the NWHI: Area 1, Nihoa Island to French Frigate Shoals; Area 2, Brooks Bank, St. Rogatien, Raita Bank, and Maro Reef; Area 3, Gardner Pinnacles; and Area 4, Laysan Island to Kure Island. The estimated exploitable populations for each area are outlined in Table 4.

Exploitable population estimates for areas 1 and 2 were derived by fitting a discrete population model as described in Amendments 7 and 9 to the FMP (see Appendix) using catch and fishing effort statistics from the commercial fishery. Commercial catch (mature unberried lobsters) and effort data from Necker Island were used to compute the exploitable population estimate of lobster in Area 1 (Fig. 14). Similar data from Maro Reef were used to estimate the lobster exploitable population in Area 2 (Fig. 15). Area-specific estimates of total exploitable population were derived by adjusting upwards the estimates of mature unberried lobster exploitable population by the proportion of berried and immature lobsters observed in the 1997 commercial landings. In Areas 3 and 4, applying the procedures described in Amendment 7 and 9 results in indeterminate exploitable population estimates. For Area 3 the model does not estimate reasonable parameter values and for Area 4 there is no recent input data (monthly commercial catch and effort metrics) for the model (commercial fishing in Area 4 ended in 1990). Recent evidence also suggests that spiny lobster recruitment patterns in Area 3 have changed. Approximately 2% of the commercial catch from Gardner Pinnacles in 1997 was immature, compared to 27% in 1995. Also, the spiny lobsters caught at Gardner Pinnacles in 1997 were the largest caught throughout the archipelago for the past few years. These observations suggest that the spiny lobster population at Gardner Pinnacles may be a remnant population, and excessive fishing could wipe them out completely. Because there is much greater uncertainty about lobster population status in these areas than in Area 1 and Area 2, there is a need for precaution in setting the corresponding lobster harvest guideline.

To help reduce the current uncertainty about population abundance in Areas 3 and 4, it would be advisable to allow experimental fishing in each of these regions, with the proviso that vessels permitted to conduct experimental fishing collect data (similar to what biological technicians collected during the 1997 fishing season) to support stock assessments. In the event that this option is exercised, it would be prudent and scientifically sound to allow the following catches to be taken:

Allowable catch

Area 3	-	20,000
Area 4	-	40,000

Allowable catches in Areas 3 and 4 are computed as  $0.13 * [CPUE_{L95} / q]$ , where  $CPUE_{L95}$  is the estimated lower 95% confidence limit of the average CPUE since 1992 for Area 3 (only 4 years of data) and since 1989 for Area 4 (only 3 years of data);  $q$  is

the catchability coefficient equal to  $2.1 \times 10^{-6}$  and  $1.9 \times 10^{-6}$  when computing the allowable catches for Areas 3 and 4, respectively.

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Table 1.--Summary of catch and effort data from federal logbooks for the NWHI lobster fishery, 1983-97.

Year	No. vessels	No. trips	No. banks	Trap hauls	Spiny lobster				Slipper lobster				Reported landings	Reported discards	Total reported catch
					Mature	Immature	Berried	Total	Mature	Immature	Berried	Total			
1983	4	19	3	64,000	158,000	51,000	10,000	218,000	18,000	6,200	1,700	26,000	176,000	68,000	244,000
1984	13	41	7	371,000	677,000	239,000	75,000	991,000	271,000	9,000	8,000	288,000	948,000	331,000	1,279,000
1985	17	66	13	1,040,000	1,002,000	355,000	132,000	1,489,000	1,029,000	96,000	121,000	1,246,000	2,031,000	705,000	2,736,000
1986	16	62	16	1,290,000	843,000	298,000	153,000	1,294,000	1,005,000	55,000	121,000	1,181,000	1,848,000	627,000	2,475,000
1987	11	40	12	805,000	393,000	233,000	101,000	727,000	395,000	36,000	43,000	474,000	788,000	414,000	1,202,000
1988	9	29	13	834,000	888,000	279,000	115,000	1,282,000	168,000	69,000	41,000	278,000	1,056,000	504,000	1,560,000
1989	11	33	13	1,070,000	944,000	369,000	169,000	1,482,000	216,000	69,000	49,000	334,000	1,160,000	655,000	1,815,000
1990	14	45	14	1,180,000	591,000	464,000	181,000	1,236,000	184,000	56,000	67,000	307,000	775,000	769,000	1,544,000
1991	9	21	5	297,000	132,000	192,000	29,000	353,000	35,000	8,700	6,000	49,700	167,000	236,000	403,000
1992	12	28	9	685,000	248,000	278,000	82,000	608,000	163,000	48,000	29,000	240,000	411,000	437,000	848,000
1993*	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----
1994	5	5	5	168,000	85,000	61,000	39,000	185,000	46,000	28,000	11,000	84,000	131,000	139,000	270,000
1995**	1	1	3	64,000	35,000	34,000	21,000	90,000	3,300	7,400	***	11,500	38,300	61,000	99,300
1996	5	5	2	115,000	123,000	----	42,000	165,000	18,000	----	4,000	22,000	187,000	2,000	189,000
1997	9	9	4	178,000	140,000	----	36,000	176,000	121,000	----	13,000	134,000	310,000	***	310,000

\* Fishery closed

\*\* Experimental fishery

\*\*\* Less than 1000 lobsters



Table 2.--Spiny lobster mean tail width (mm) and mature, immature, and berried catches by statistical area based on data collected by biological technicians during the 1995 commercial fishery. Numbers in ( ) represent percentage.

Statistical area	N	Mean tail width (mm)	Number mature lobsters	Number immature lobsters	Number berried lobsters
1	1,758	48.7	399 (22.7)	891 (50.7)	468 (26.6)
2	2,666	49.8	786 (29.5)	1,208 (45.3)	672 (25.2)
3	859	50.7	301 (35.1)	324 (37.7)	234 (27.2)
4	2,278	52.6	1,010 (44.3)	521 (22.9)	747 (32.8)
5	3,569	53.2	1,511 (42.3)	530 (14.9)	1,528 (42.8)

Table 3.--Bank-specific SPRs from 1995 to 1997.

Year	Bank	
	Necker Island	Maro Reef
1995	0.78	0.97
1996	0.52	1.00
1997	0.52	0.83

Table 4.--Area-specific estimates of lobster exploitable population (species combined) in the NWHI on July 1, 1998.

Area	Exploitable population (numbers)
1	538,000
2	615,000
3	Indeterminate
4	Indeterminate

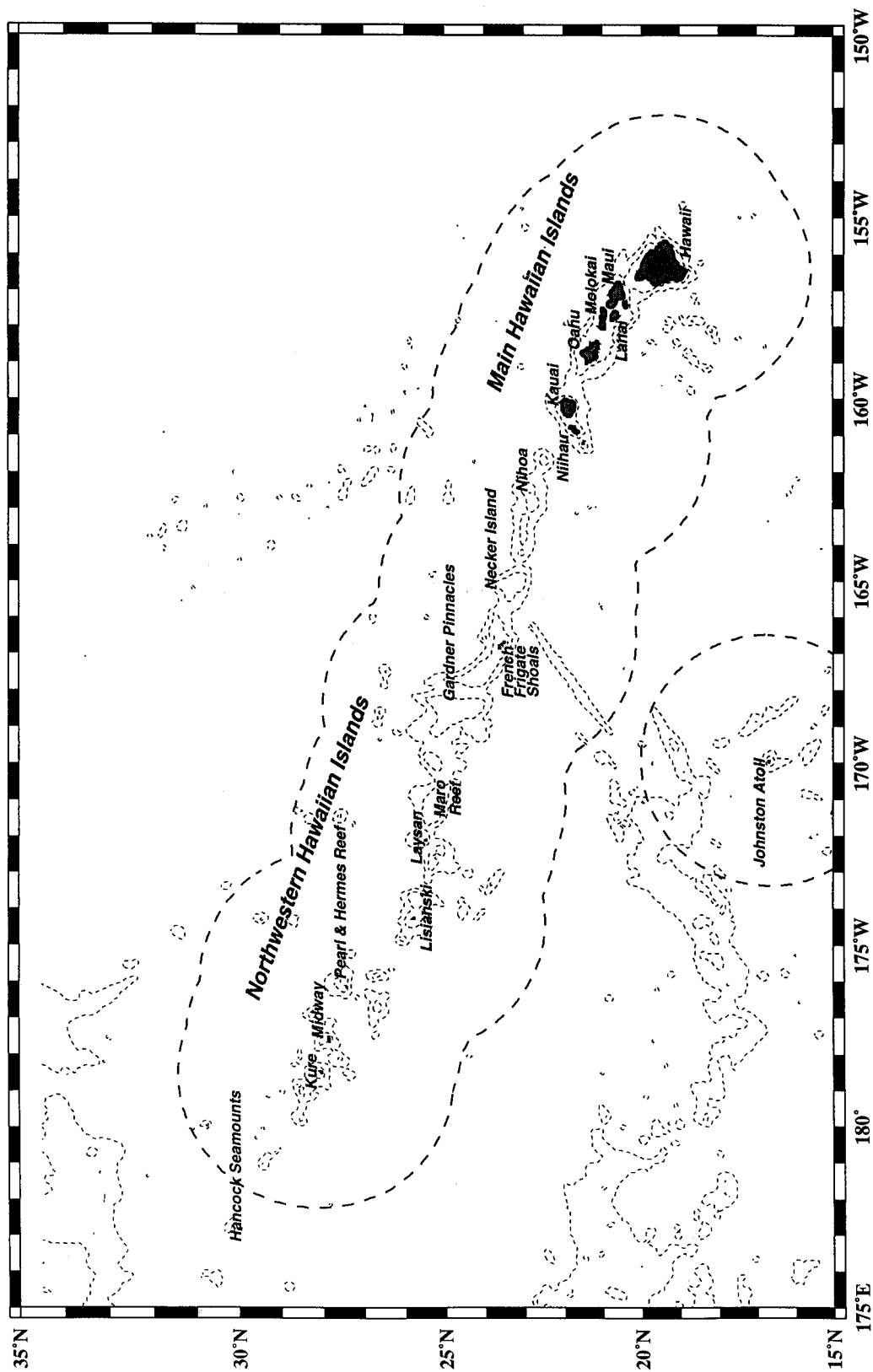


Figure 1.—The Hawaiian Archipelago.

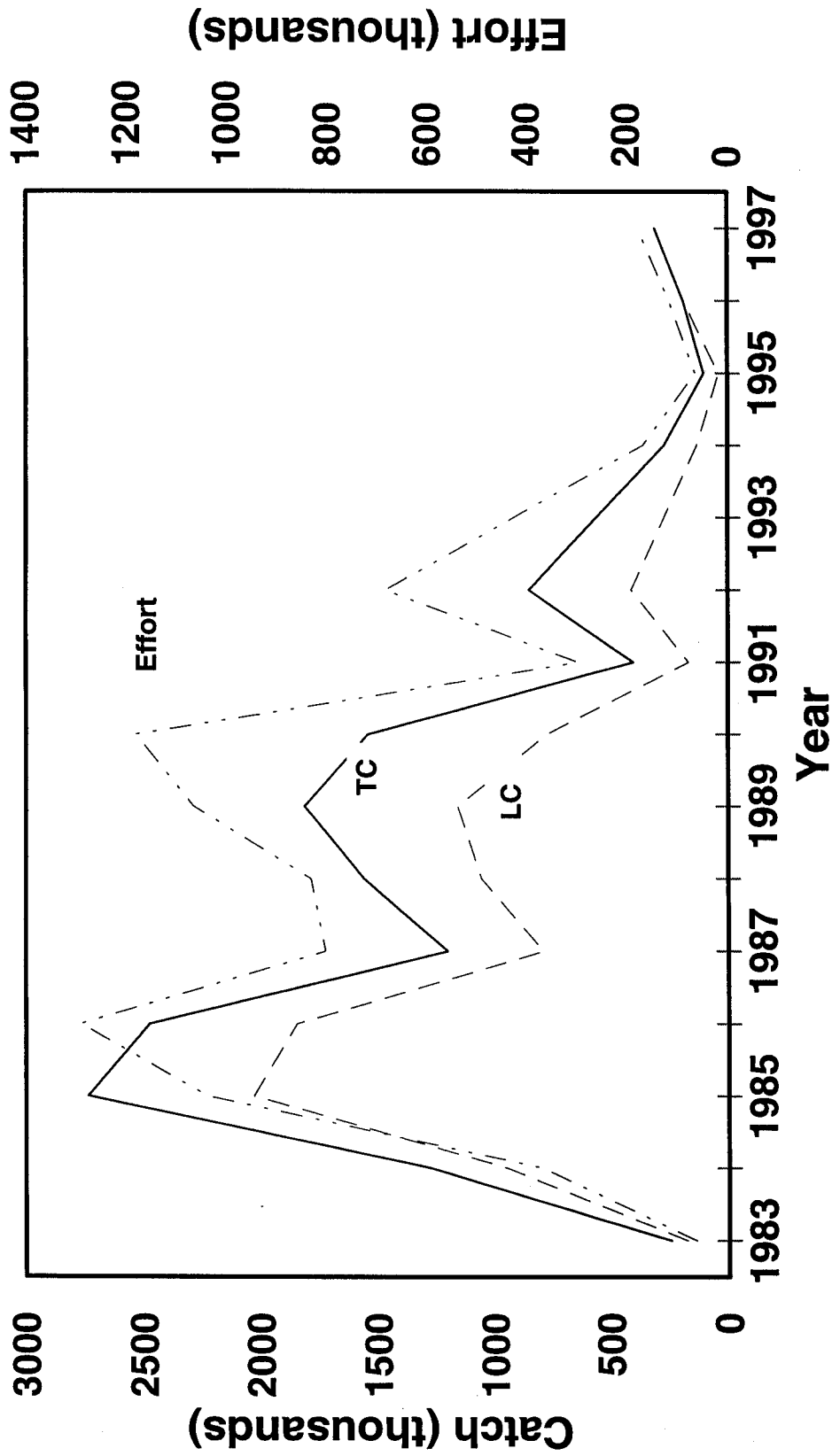


Figure 2.--Annual metrics of reported total catch (TC), mature catch (LC), and fishing effort (trap hauls) in the NWHI commercial lobster trap fishery.

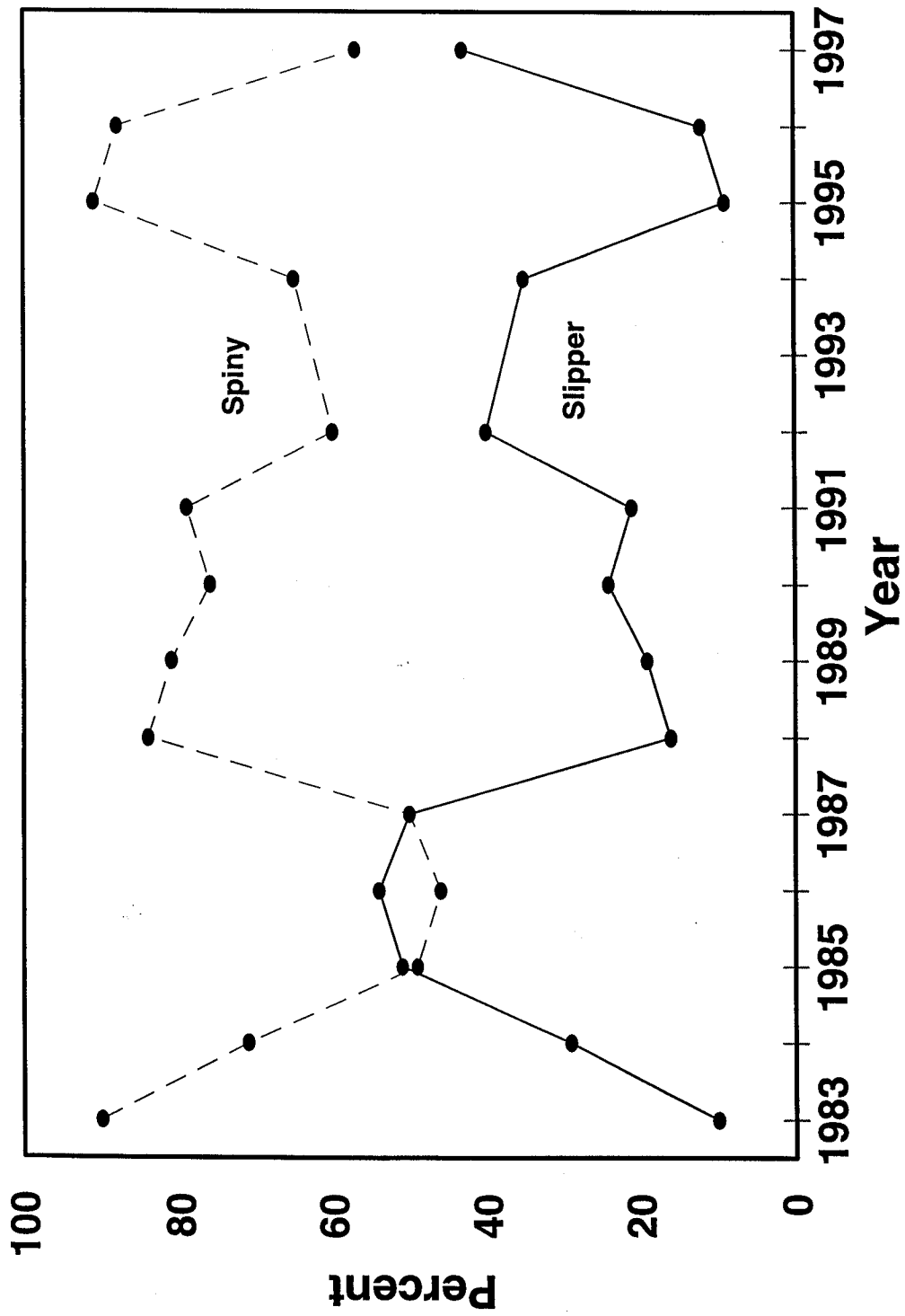


Figure 3.--Annual percentages of mature spiny and slipper lobster catches (see text for legal definition).

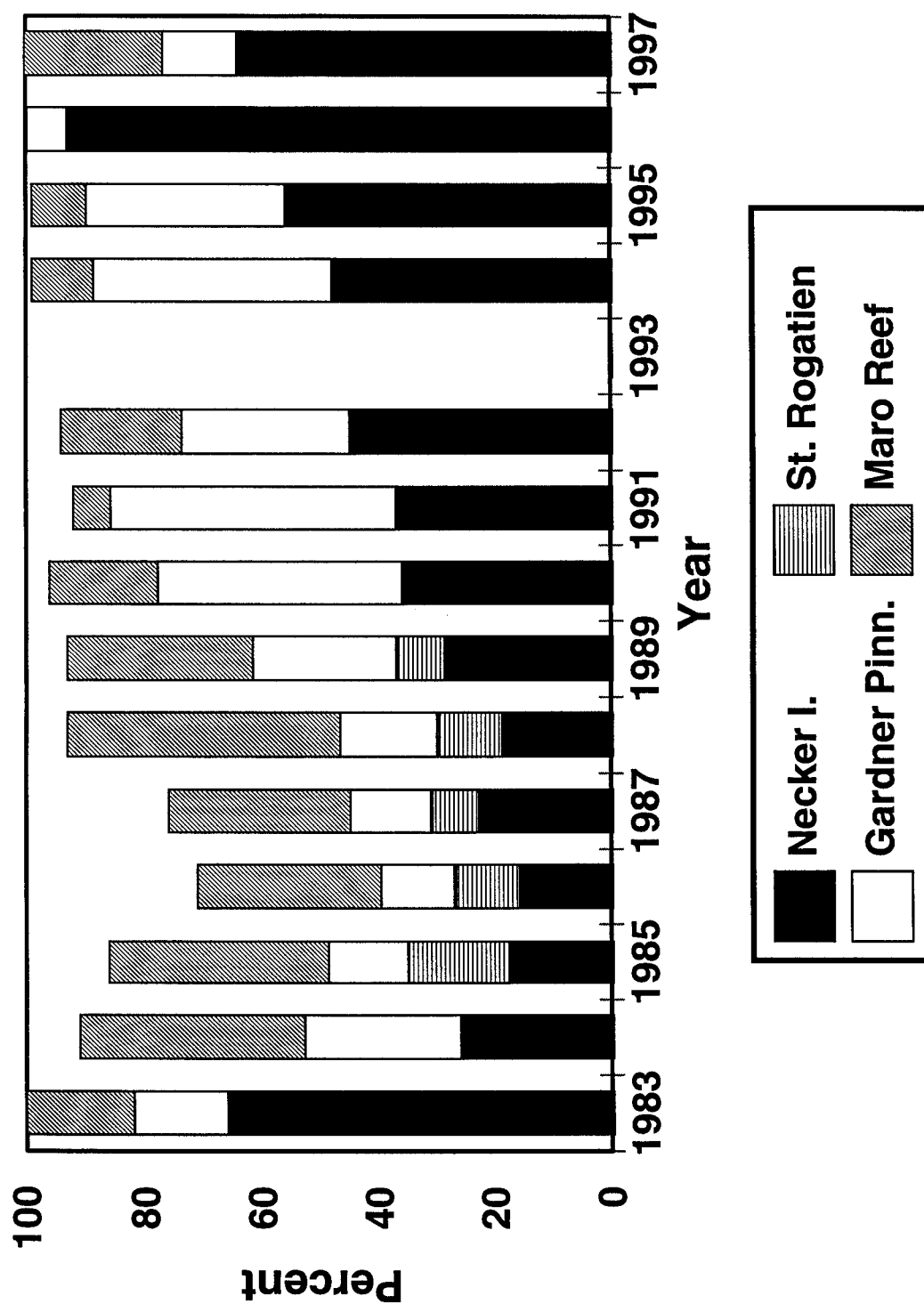


Figure 4.--Annual percentages of total fishing effort (trap hauls) reported at Necker Island (NI), Gardner Pinnacles (GP), St. Rogation (SR), and Maro Reef (MR).

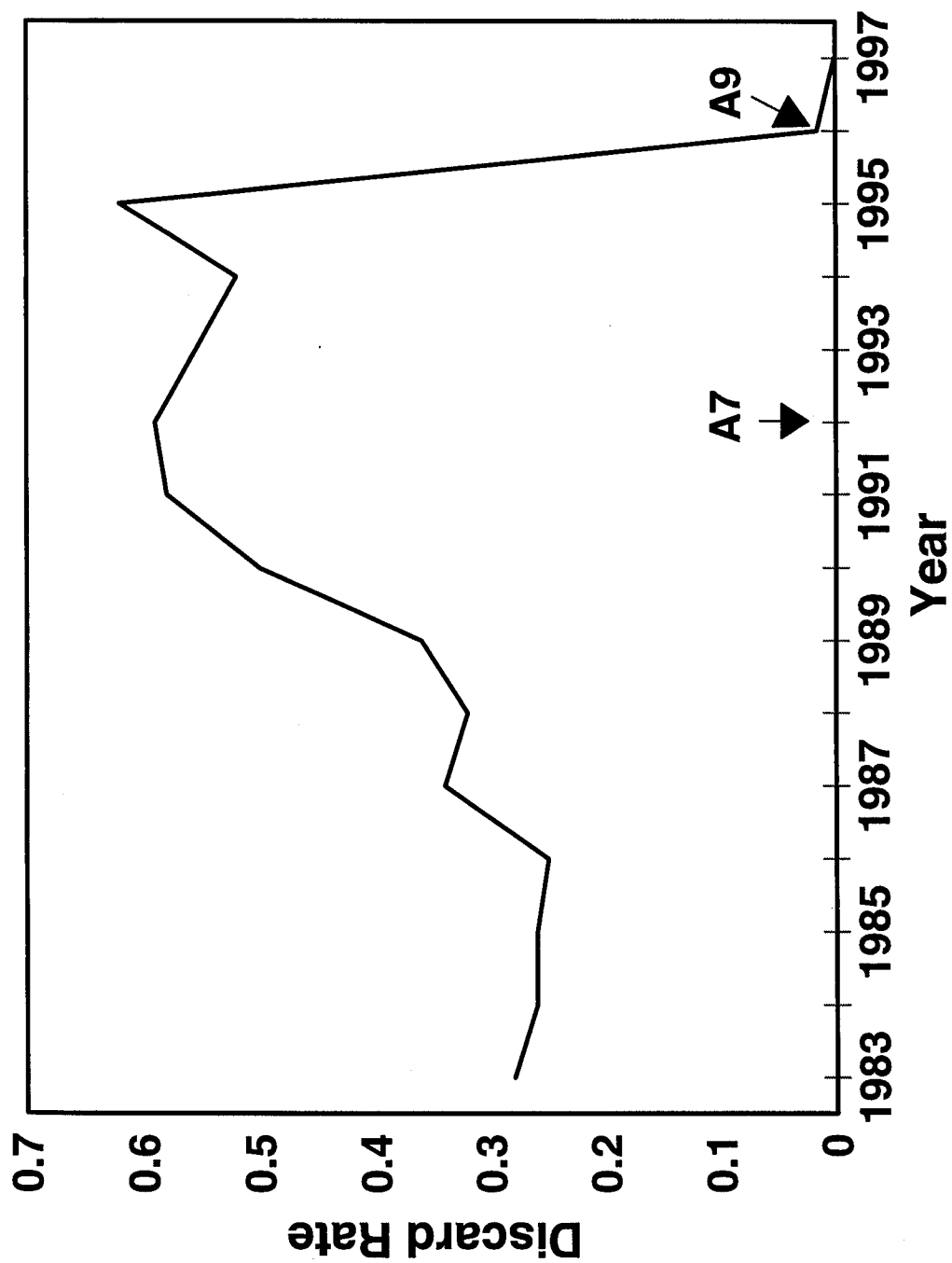


Figure 5.--Annual estimates of the reported discard rate for lobsters from the NWHI lobster trap fishery. A7 and A9 show when Amendments 7 and 9 were implemented, respectively.

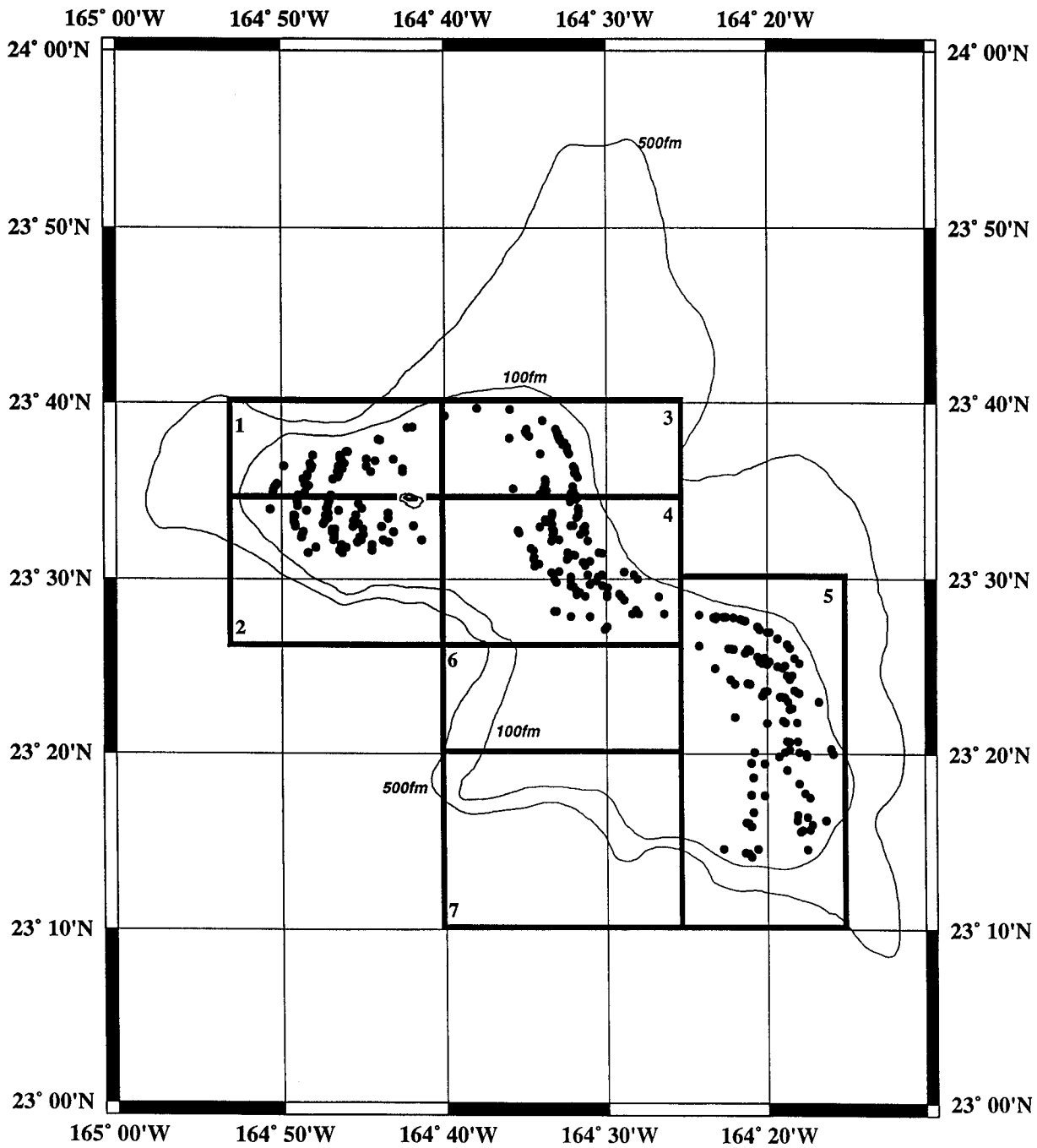


Figure 6.--The location of sampled strings during the 1995 commercial fishery at Necker Island. The 7 statistical areas are based on reported commercial fishing areas.



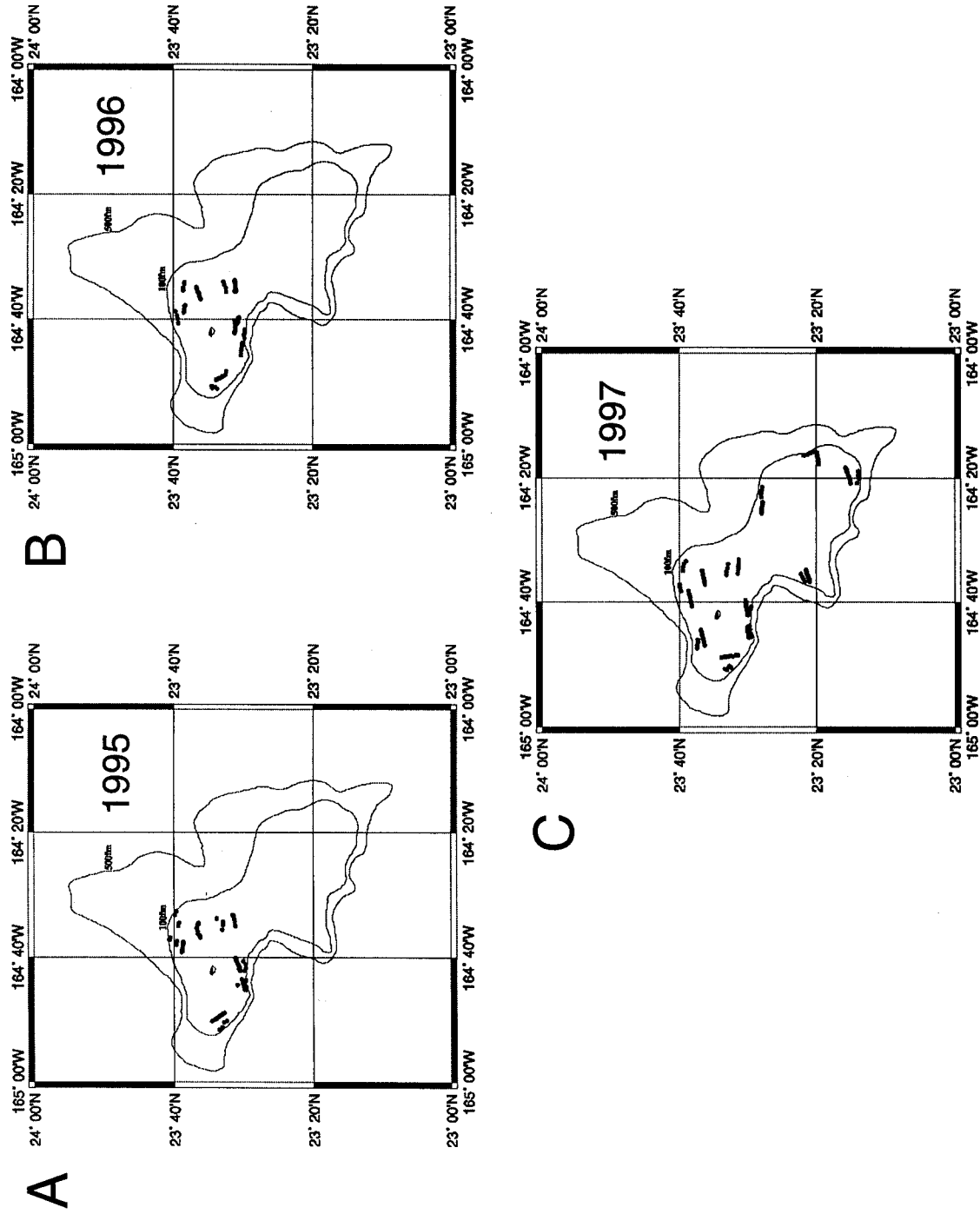


Figure 7.--Research trapping stations at Necker Island, 1995-97.

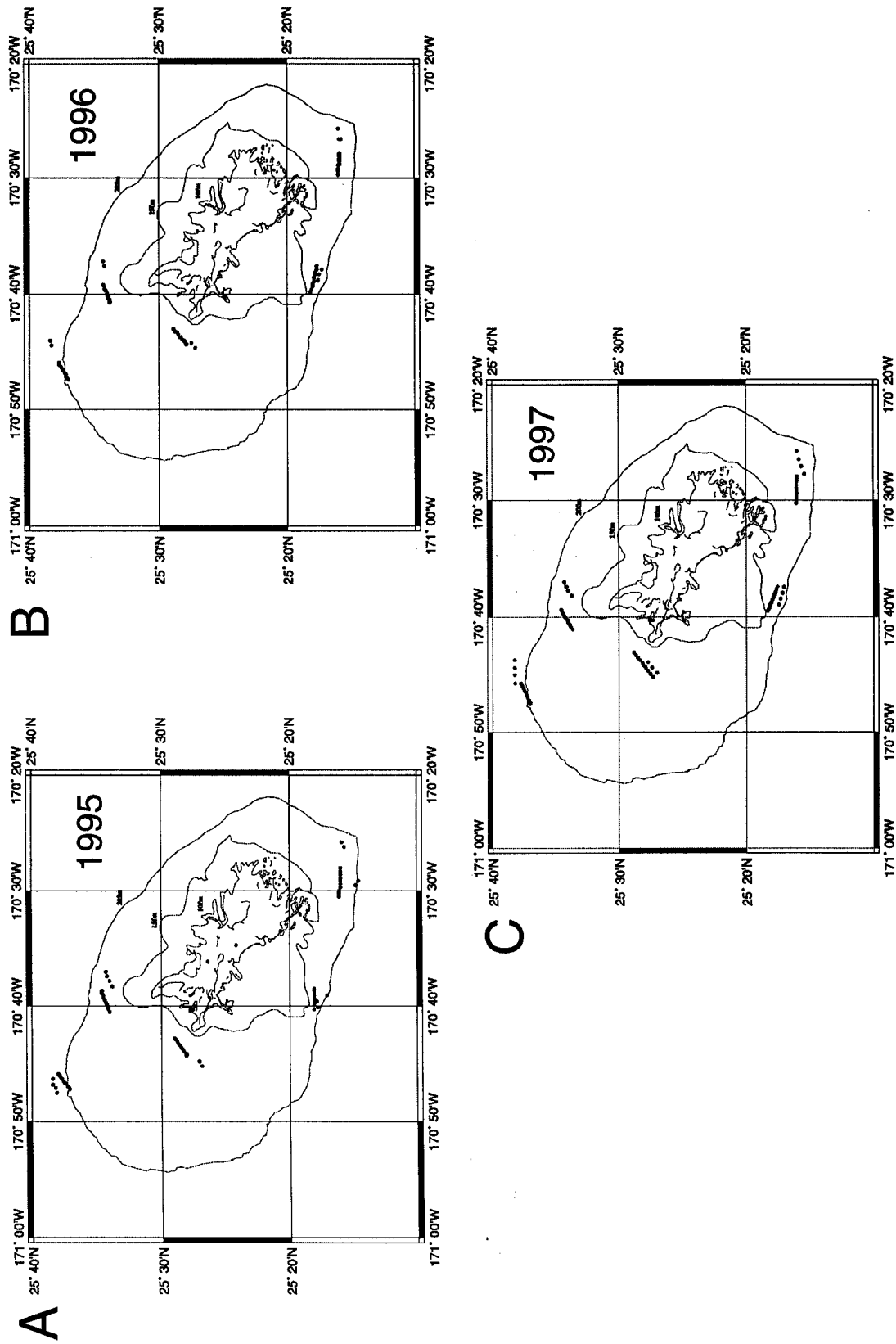


Figure 8.--Research trapping stations at Maro Reef, 1995-97.

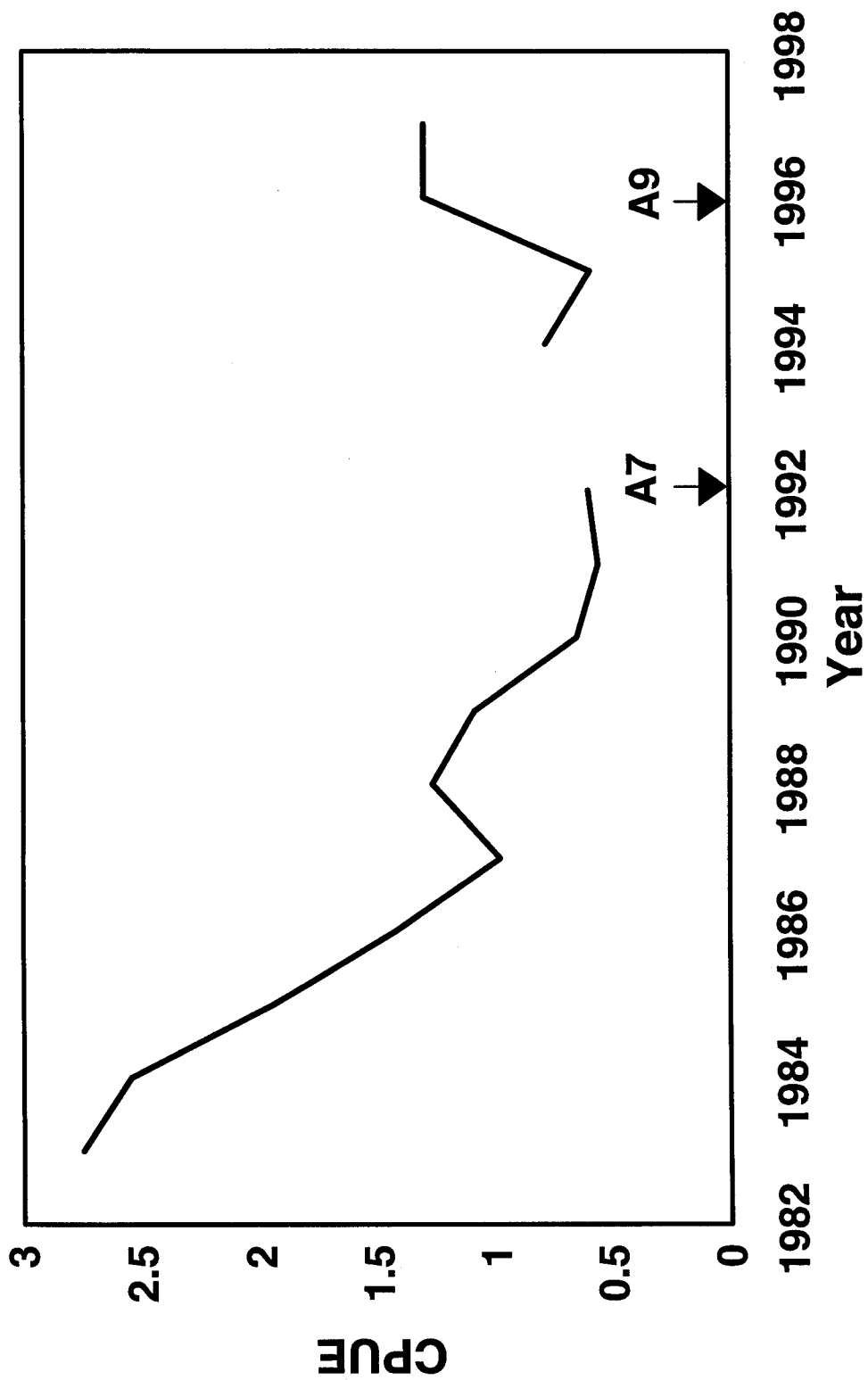


Figure 9.--Annual commercial CPUE for the NWHI lobster trap fishery, 1983-97. A7 and A9 show when Amendments 7 and 9 were implemented, respectively.

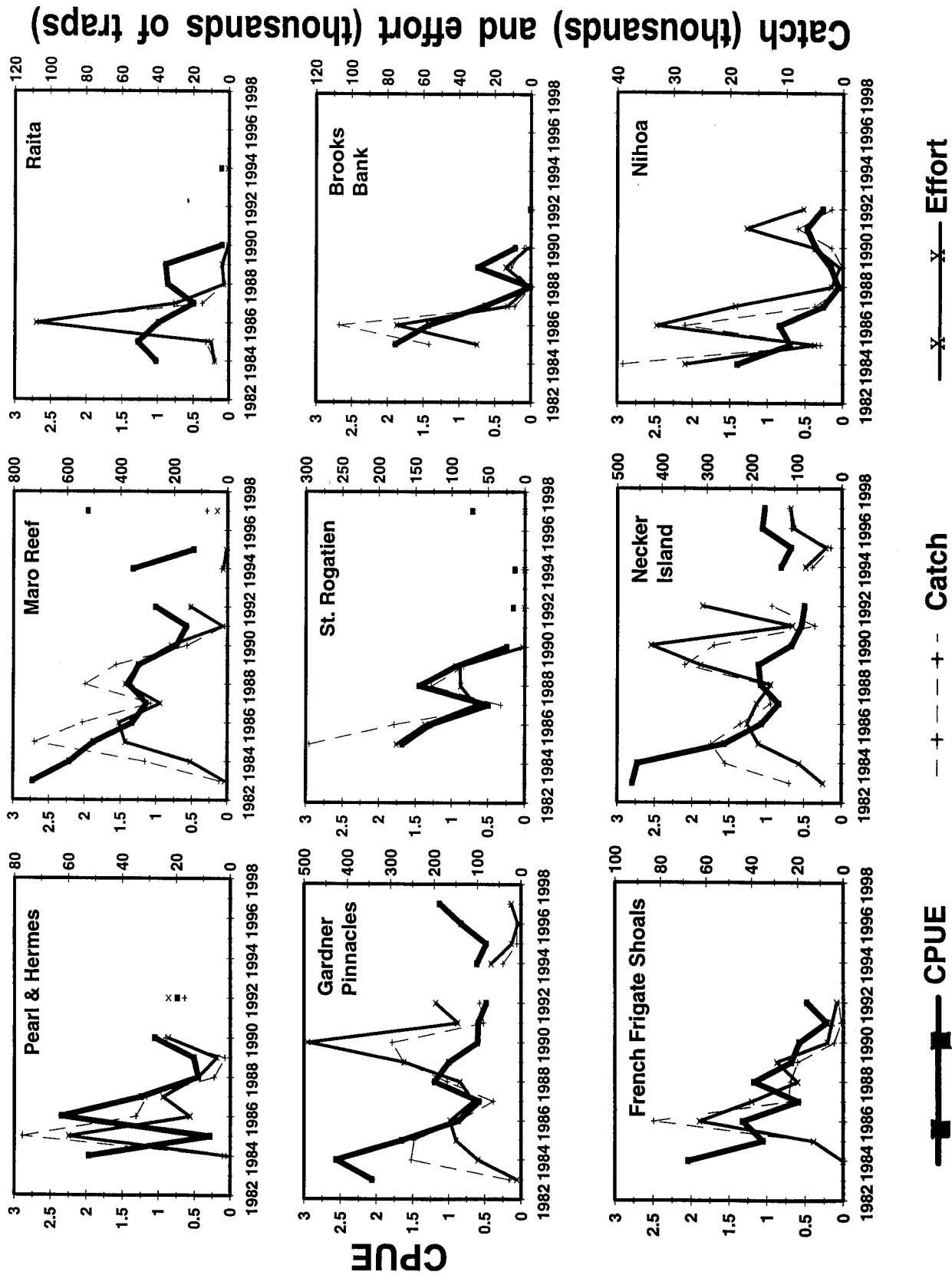


Figure 10.--Bank-specific annual metrics of CPUE, fishing effort (trap hauls) and catch from the NWHI lobster fishery.

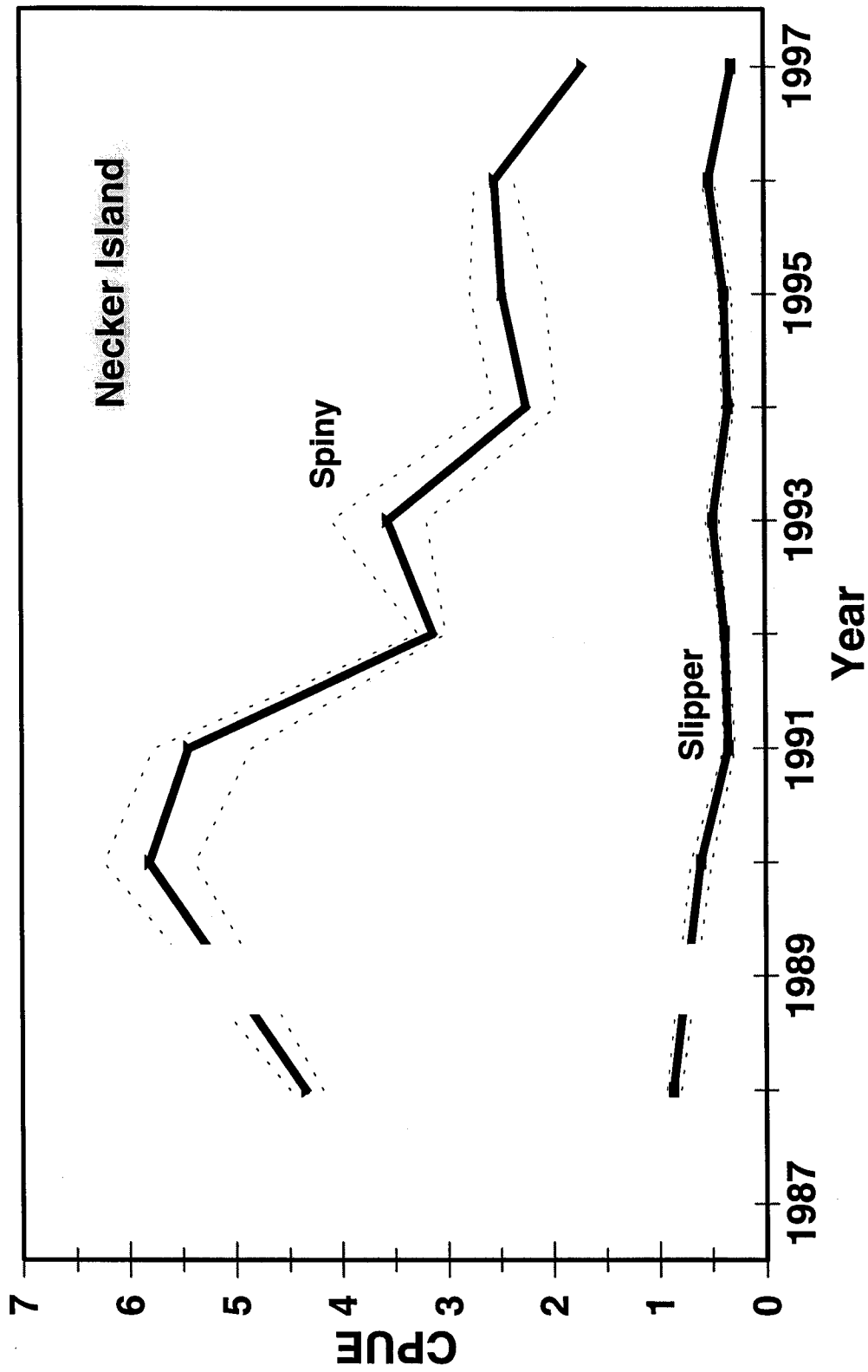


Figure 11.--Annual metrics of spiny and slipper lobster CPUEs from the Townsend Cromwell research surveys at Necker Island.

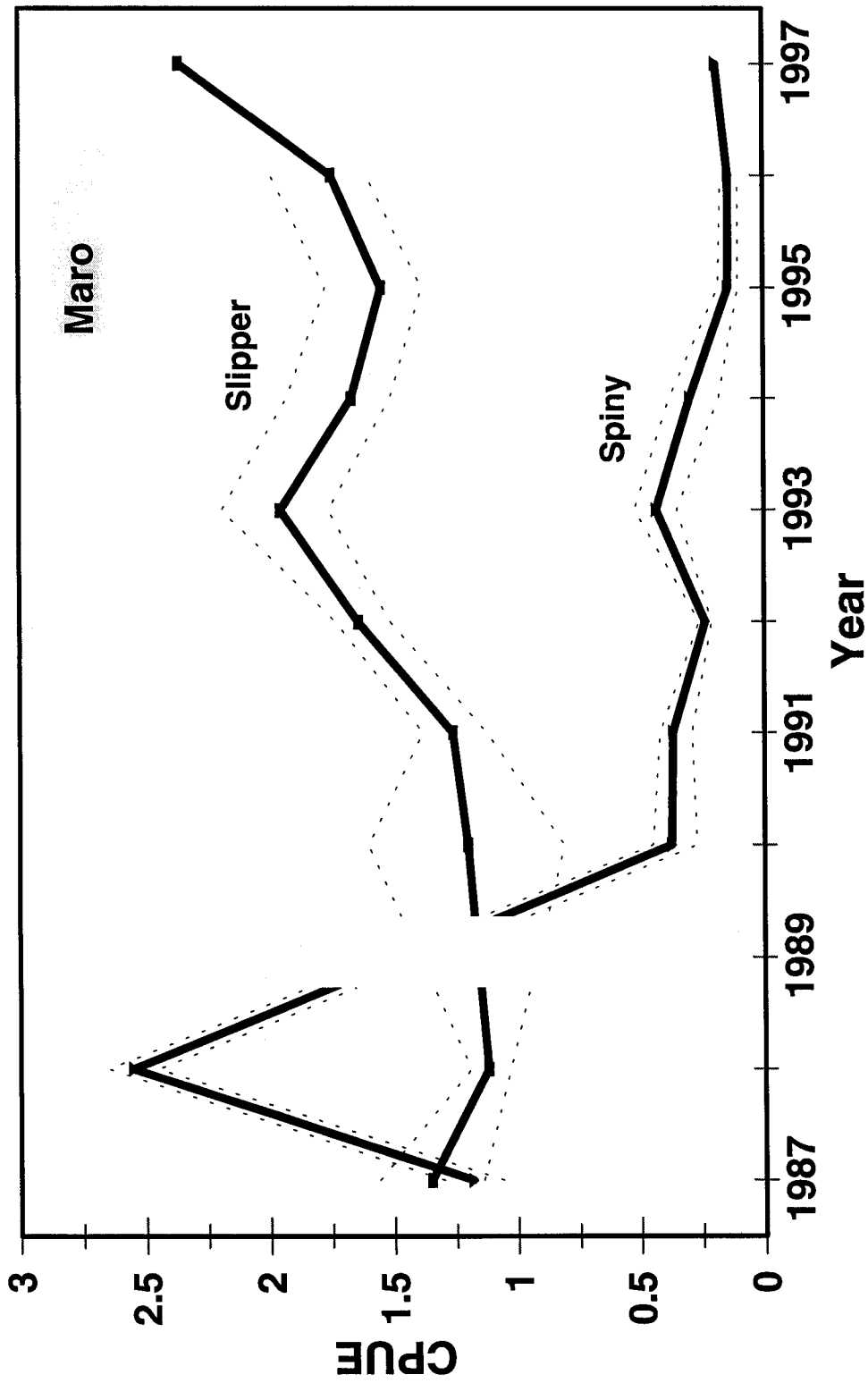


Figure 12.--Annual metrics of spiny and slipper lobster CPUEs from the Townsend Cromwell research surveys at Maro Reef.

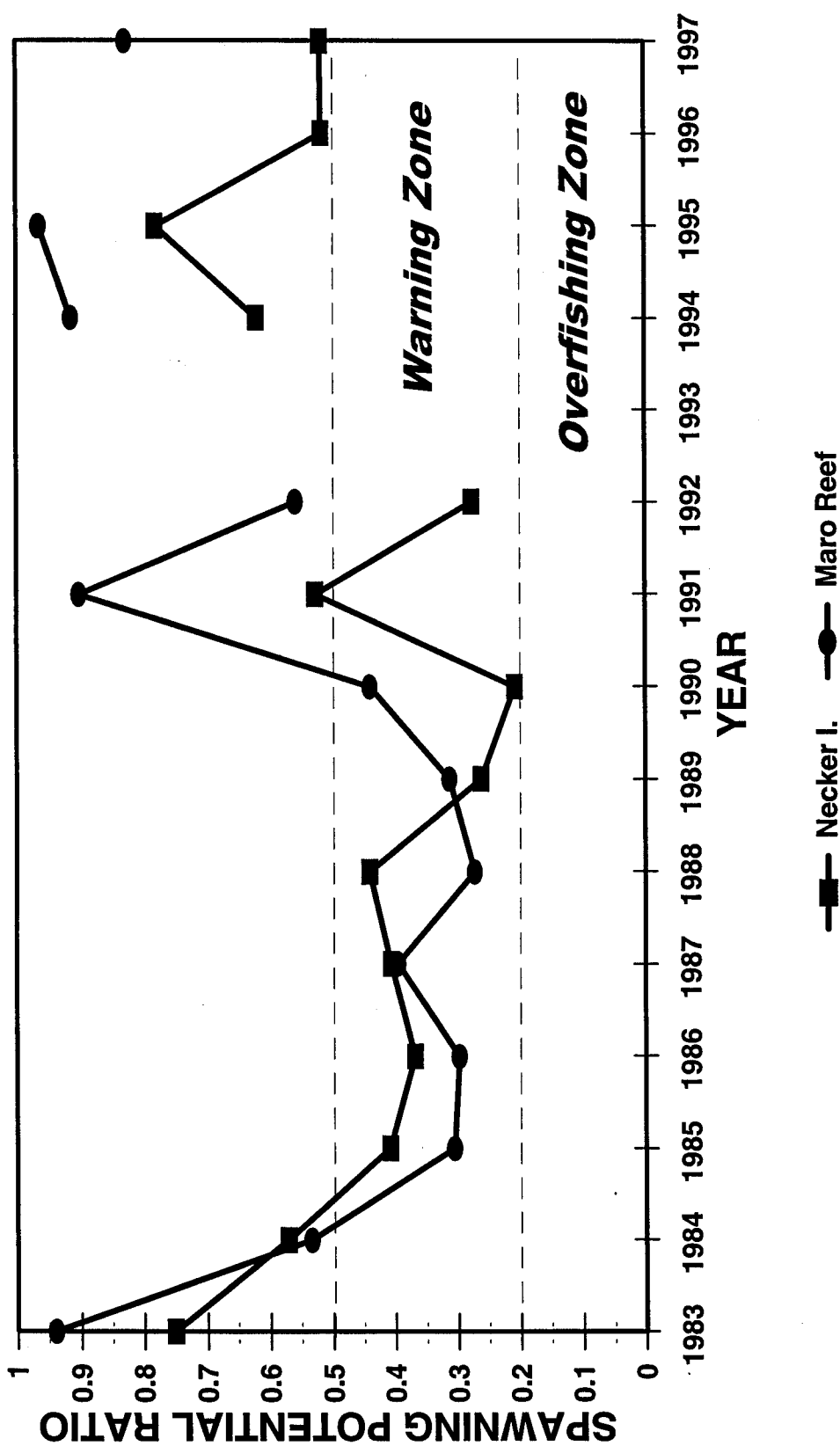


Figure 13.--Metrics of the spawning potential ratio (SPR) for Necker Island and Maro Reef, 1983-97.

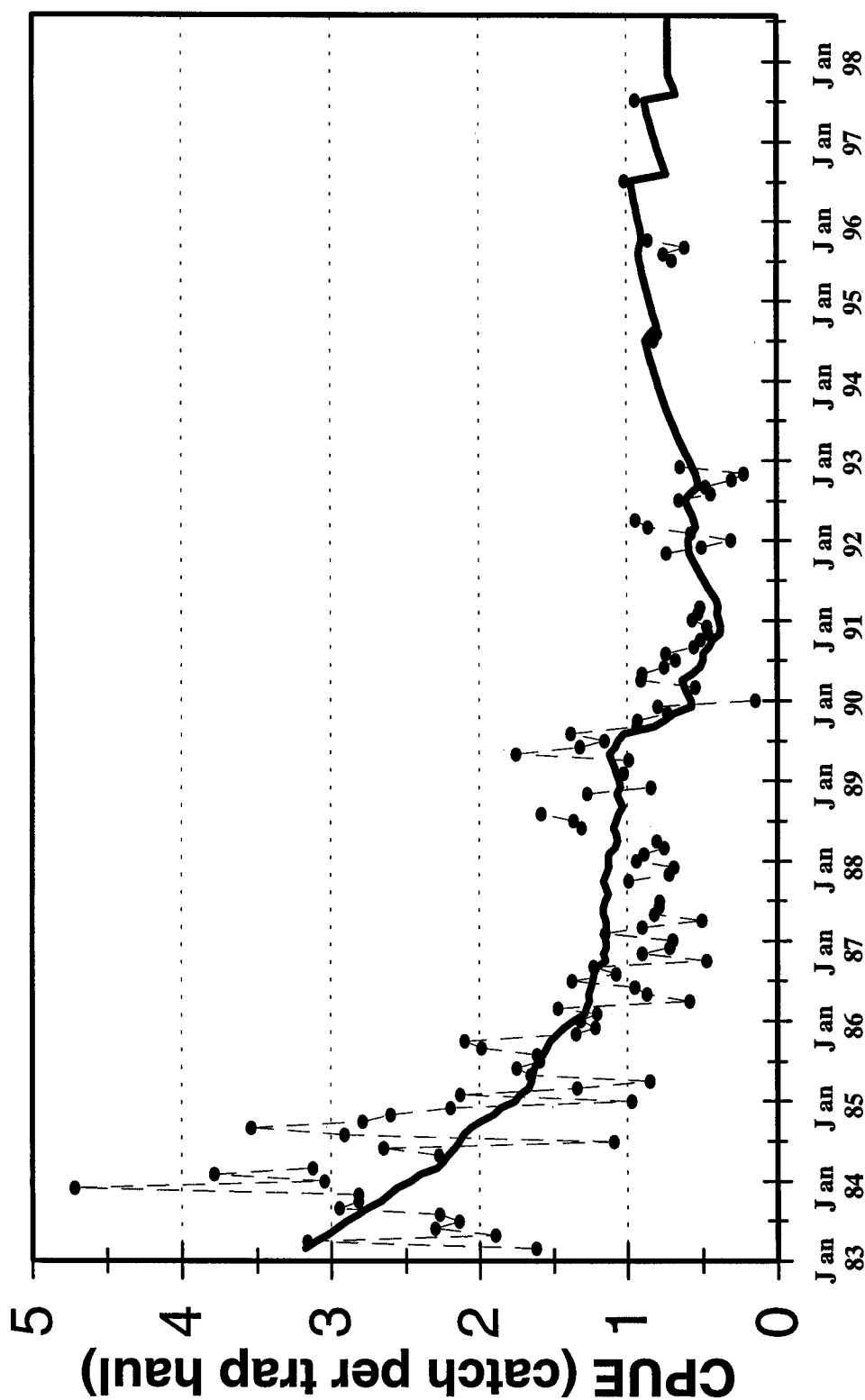


Figure 14.--Necker Island monthly mature unberried lobster CPUE (dashed line) and fitted population model (solid line) used to project July 1998 lobster population.



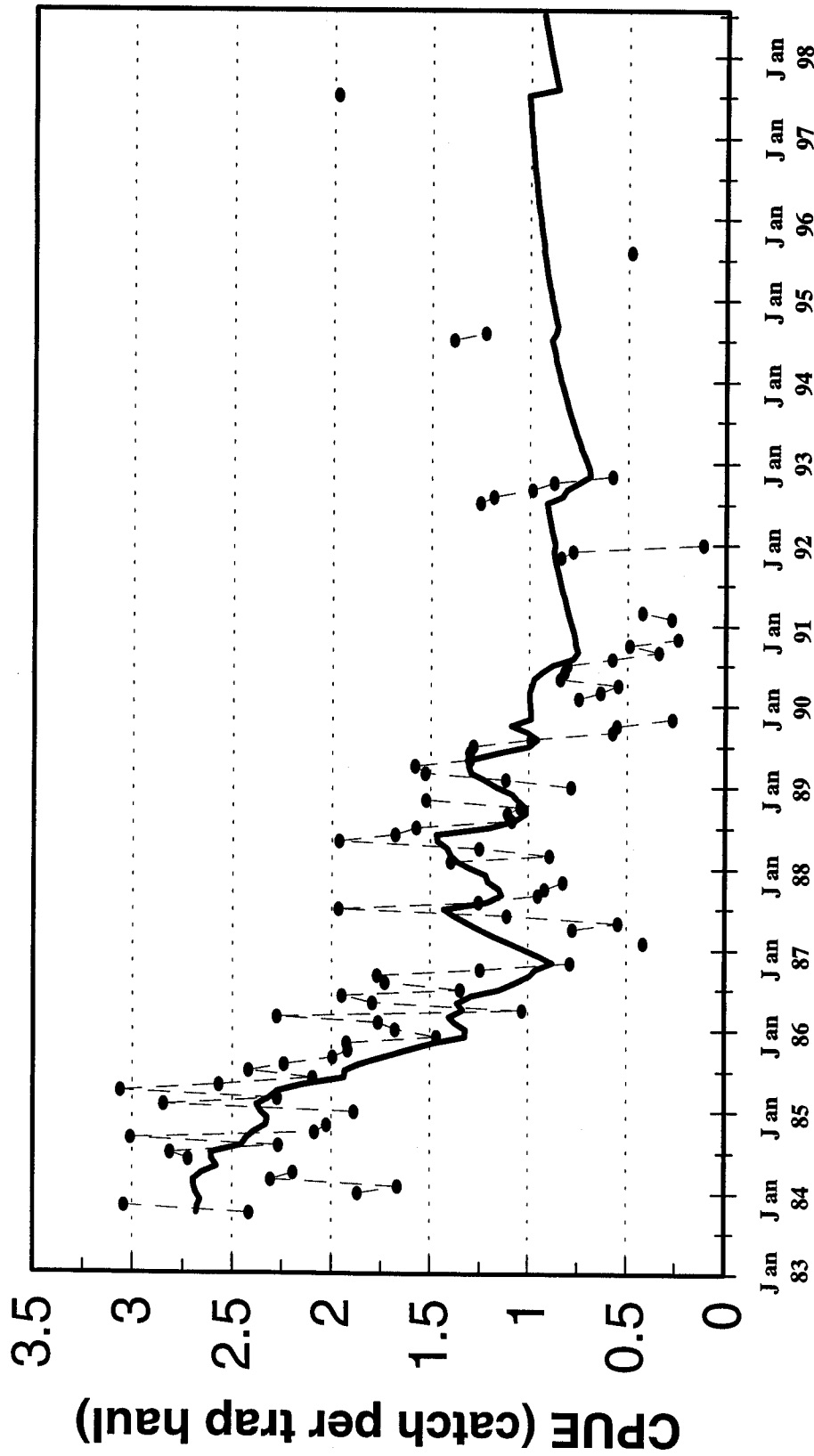


Figure 15.--Maro Reef monthly mature unberried lobster CPUE (dashed line) and fitted population model (solid line) used to project July 1998 lobster population.

## APPENDIX

### Estimation of Lobster Population Model Parameters

NWHI lobster population dynamics have been described by a difference equation incorporating a population abundance index and known fishery removals (Polovina et al., 1995). Assume an initial population size of  $N_1$  harvestable lobsters at the start of time interval 1. The population size at the beginning of any subsequent time interval will be determined by the net effects of natural mortality, catch removals, and recruitment. In general, for successive time intervals the relationship is :

$$\begin{aligned} N_{i+1} &= N_i - N_i(1 - S) - C_i + R \\ &= N_i S - C_i + R \end{aligned}$$

where  $N_i$  = number of harvestable-size lobsters in the population at the beginning of time period (month)  $i$ , ( $i = 1, 2, \dots, n$ )

$S$  = monthly survival rate in the absence of fishing (assumed constant),

$C_i$  = catch of harvestable-size lobsters in month  $i$ , and

$R$  = number of lobsters recruiting to the population of harvestable-size lobsters in month  $i$  (assumed constant).

In terms of the initial population size, the abundance at the start of interval  $i$  can be written as:

$$N_i = \begin{cases} N_1 & \text{for } i = 1 \\ N_1 S^{i-1} - \sum_{j=1}^{i-1} C_j S^{i-j-1} + \sum_{j=1}^{i-1} R S^{i-j-1} & \text{for } 2 \leq i \leq n \end{cases}$$

Here we assume that recruitment is constant over time. Alternatively, we may suppose that recruitment is constant at one level,  $R_1$ , up to time  $\tau$ , then changes to a second constant level,  $R_2$ . There is evidence that this more complex model is appropriate for NWHI lobsters (Polovina and Mitchum, 1992; Polovina et al., 1994; Wetherall et al., 1995). With 2-stanza recruitment the population dynamics now become:

$$N_i = \begin{cases} N_1 & \text{for } i = 1 \\ N_1 S^{i-1} - \sum_{j=1}^{i-1} C_j S^{i-j-1} + \sum_{j=1}^{i-1} R_1 S^{i-j-1} & \text{for } 2 \leq i < \tau+1 \\ N_1 S^{i-1} - \sum_{j=1}^{i-1} C_j S^{i-j-1} + S^{i-\tau} \sum_{j=1}^{\tau-1} R_1 S^{j-1} + \sum_{j=\tau}^{i-1} R_2 S^{j-\tau} & \text{for } \tau+1 \leq i \leq n \end{cases}$$

or

$$N_i = \begin{cases} N_1 & \text{for } i = 1 \\ N_1 S^{i-1} - S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j} + R_1 \frac{(1-S^{i-1})}{(1-S)} & \text{for } 2 \leq i < \tau+1 \\ N_1 S^{i-1} - S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j} + R_1 S^{i-\tau} \frac{(1-S^{\tau-1})}{(1-S)} + R_2 \frac{(1-S^{i-\tau})}{(1-S)} & \text{for } \tau+1 \leq i \leq n \end{cases}$$

The absolute population size is unobservable, but may be indexed by catch-per-unit effort (CPUE) statistics if catchability is constant. Polovina et al. (1995) assumed that average CPUE was proportional to the population size at the beginning of the time interval. Let  $U_i$  denote the CPUE in time interval  $i$ . Then the abundance index is:

$$U_i = q N_i$$

where  $q$  is the catchability coefficient. Substituting the above population equations, the abundance index can be written as:

$$U_i = \begin{cases} q N_1 & \text{for } i = 1 \\ q N_1 S^{i-1} - q S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j} + q R_1 \frac{(1-S^{i-1})}{(1-S)} & \text{for } 2 \leq i < \tau+1 \\ q N_1 S^{i-1} - q S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j} + q R_1 S^{i-\tau} \frac{(1-S^{\tau-1})}{(1-S)} + q R_2 \frac{(1-S^{i-\tau})}{(1-S)} & \text{for } \tau+1 \leq i \leq n \end{cases}$$

This nonlinear model of the expected CPUE during time period  $i$  can be used to estimate the parameters  $N_1$ ,  $S$ ,  $q$ ,  $R_1$ , and  $R_2$  using least-squares or other methods. Estimation is greatly simplified if we are willing to assume the survival rate,  $S$ , is known. Then the model becomes a linear function of the remaining unknowns, and the parameters can be estimated using a variety of multiple linear regression routines (we used a simple Quattro Pro spreadsheet). The regression model takes the form:

$$U_i = \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \epsilon_i$$

where  $\epsilon_i$  is a random error term with expectation  $E(\epsilon_i) = 0$ . The parameter relationships between the model of population dynamics and the linear regression model are given by  $\beta_1 = qN_1$ ,  $\beta_2 = -q$ ,  $\beta_3 = qR_1$ , and  $\beta_4 = qR_2$  and the independent variables for the regression are:

Time	$X_1$	$X_2$	$X_3$	$X_4$
$i = 1$	1	0	0	0
$1 < i \leq \tau$	$S^{i-1}$	$S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j}$	$\frac{(1 - S^{i-1})}{(1 - S)}$	0
$\tau < i \leq n$	$S^{i-1}$	$S^{i-1} \sum_{j=1}^{i-1} C_j S^{-j}$	$S^{i-\tau} \frac{(1 - S^{\tau-1})}{(1 - S)}$	$\frac{(1 - S^{i-\tau})}{(1 - S)}$

Once estimates of the regression parameters are in hand, estimates of the population parameters may be parsed out as follows:

$$\hat{q} = -\hat{\beta}_2$$

$$\hat{N}_1 = -\hat{\beta}_1/\hat{\beta}_2$$

$$\hat{R}_1 = -\hat{\beta}_3/\hat{\beta}_2$$

$$\hat{R}_2 = -\hat{\beta}_4/\hat{\beta}_2$$